An Integrated Assessment of the Impacts of Air Pollution on Health in Eastern China: A valuation with implications for future air pollution and energy policies

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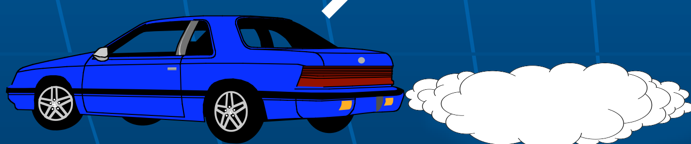
Integrated Assessment of
Marginal Benefits of Air Pollution Mitigation Strategies

Prepare baseline emission inventory

Model resulting changes in concentrations of air pollutants



Model Changes in Emissions of reactive pollutants and GHG

$ **Estimate costs of emission reductions**

Model changes in human exposure

Model Changes in Health Effects

Model Value of Health Benefits

Adapted from slide from Dan Greenbaum

A Case Study
Evaluating Impacts of Air Pollution in eastern China on Public Health: Implications for Future Air Pollution and Energy Policies

Questions to be addressed

- How severe was air pollution in eastern China in 2000?
  - How large were the resulting health impacts?
  - What was the monetary value of these health impacts?
- How severe will air pollution be in 2020 if energy demand increases but
  - No additional pollution controls are implemented (BAU)?
  - Best available control technology (BACT) is used?
  - Advanced Coal Gasification Technology (ACGT) is used?

    ACGT eliminates most air pollutant emissions, and permits sequestration of CO2
- How large will the health impacts be in 2020 under BAU?
  - What is the monetary value of these damages?
- To what extent can BACT and ACGT reduce health impacts in 2020?
  - What is the monetary value of these health benefits?

Integrated Assessment Approach

I. Develop a high-resolution regional anthropogenic emission inventory that explicitly includes energy end-use sector/activity.

II. Simulate ambient concentrations of primary and secondary PM and gaseous species using Models-3/CMAQ.

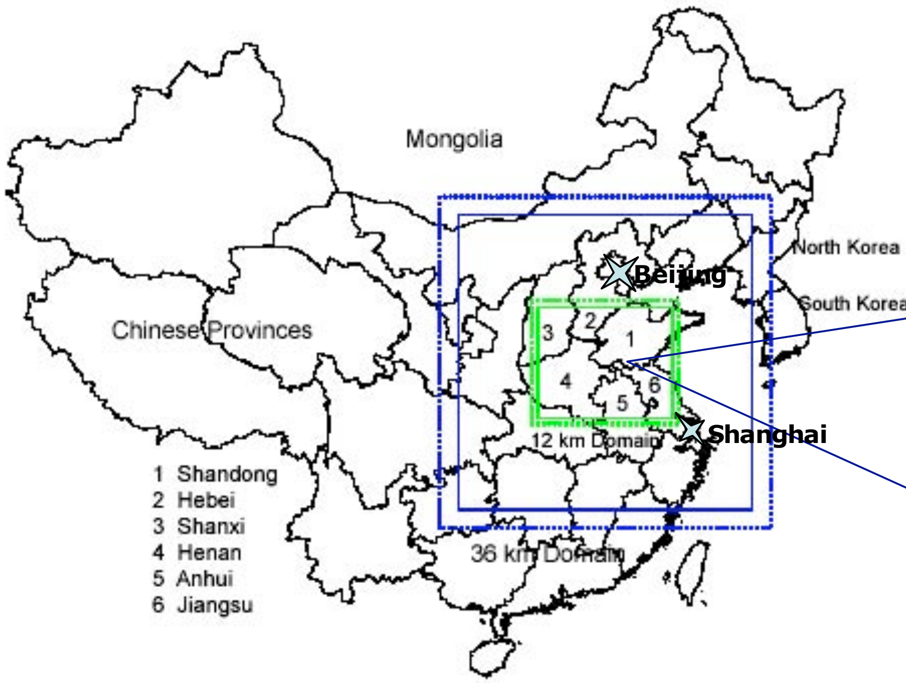
III. Estimate physical health impacts (mortality, YOLL, and morbidity) associated with air pollution exposure in 2000 and for three possible scenarios in 2020: BAU, BACT, and ACGT.

IV. Quantify costs resulting from health impacts of air pollution exposure and benefits of utilizing BACT or ACGT rather than BAU.

Integrated Assessment Structure

Intermediate Outcome	Method
1) Energy consumption and technology scenarios	Collect energy consumption and technology data for base year 2000, project energy demand for 2020, and develop pollution control and alternative energy scenarios for 2020.
2) Emission inventory	Estimate anthropogenic emissions based on levels of energy consumption and emission factors
3) Ambient air pollution concentrations	Use CMAQ to simulate hourly concentrations of pollutants for four seasons of 2000, 2020 and for future alternative scenarios.
4) Human exposure	Calculate exposure based on calculated ambient concentrations and population distributions.
5) Health Impacts	Estimate number of deaths, years of life lost and illness based on concentration-response functions from literature.
6) Economic costs	Estimate economic value of health impacts.

Study Region



Zaozhuang

Population: 3.5 million (37% urban)
Per capita GDP: 2000US$ 842
Area: 4550 km^2
Coal production: 20 mil tons
Coal consumption: 3.1 mil tons

Population in model domain: 281 million

Why select Zaozhuang in Shandong Province for a case study?

- Rich in coal, particularly high sulfur coal
- 85% of energy services provided by coal with substantial coal export
- Region of particularly poor air quality that is likely to worsen
- Region with potential to use high-sulfur coal cleanly
- A medium-sized municipality with potential to be replicated

PART I

Emission Inventory Development

Emission Inventory Development (1)

$$E_{j,k,l,m,n} = A_{j,k,l,m,n} * EF_{j,k,l,m,n}$$

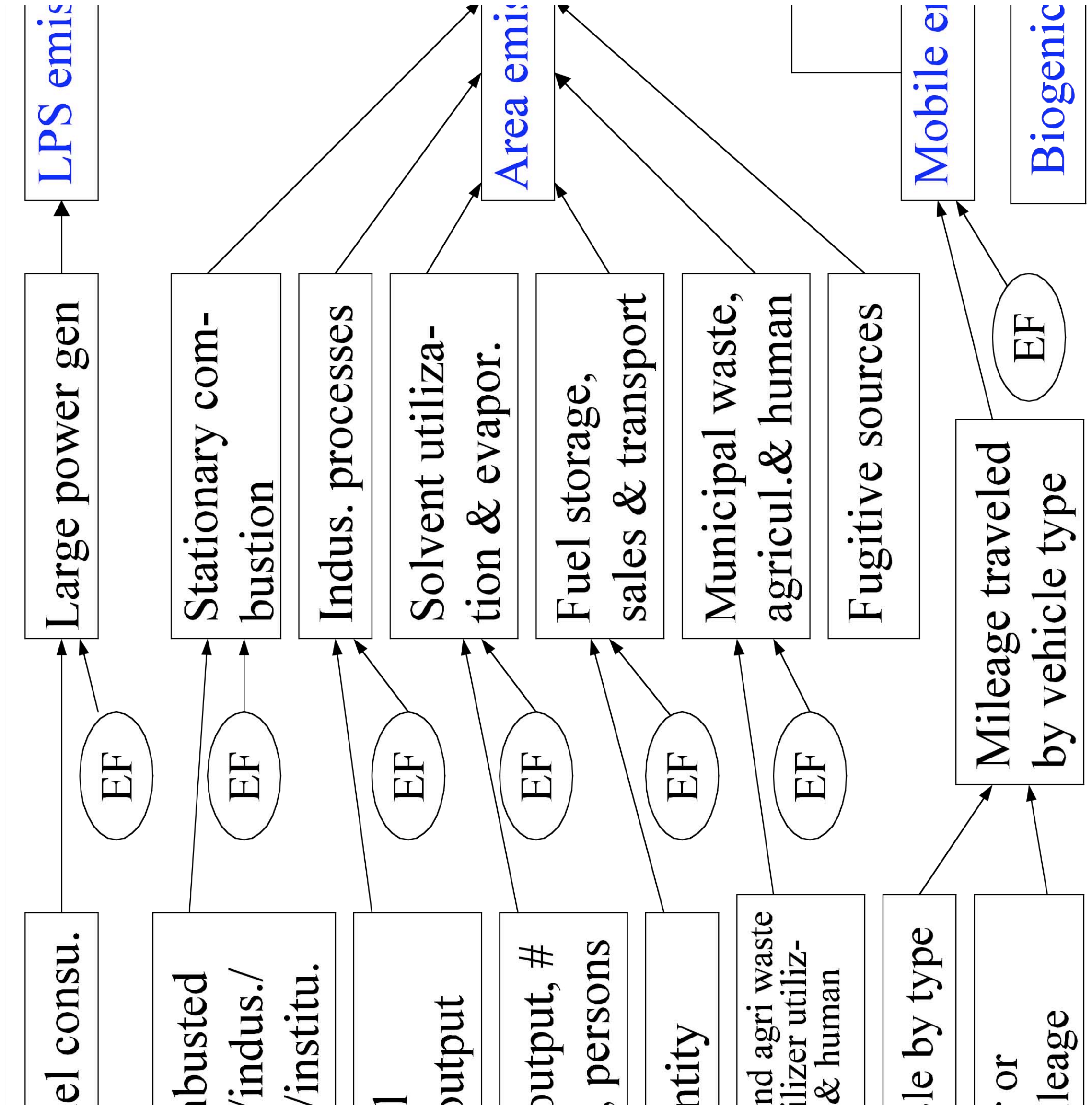
E = emissions
A = activity rate
EF = emission factor

j = species
k = municipality
l = sector
m = fuel or activity type
n = abatement technology

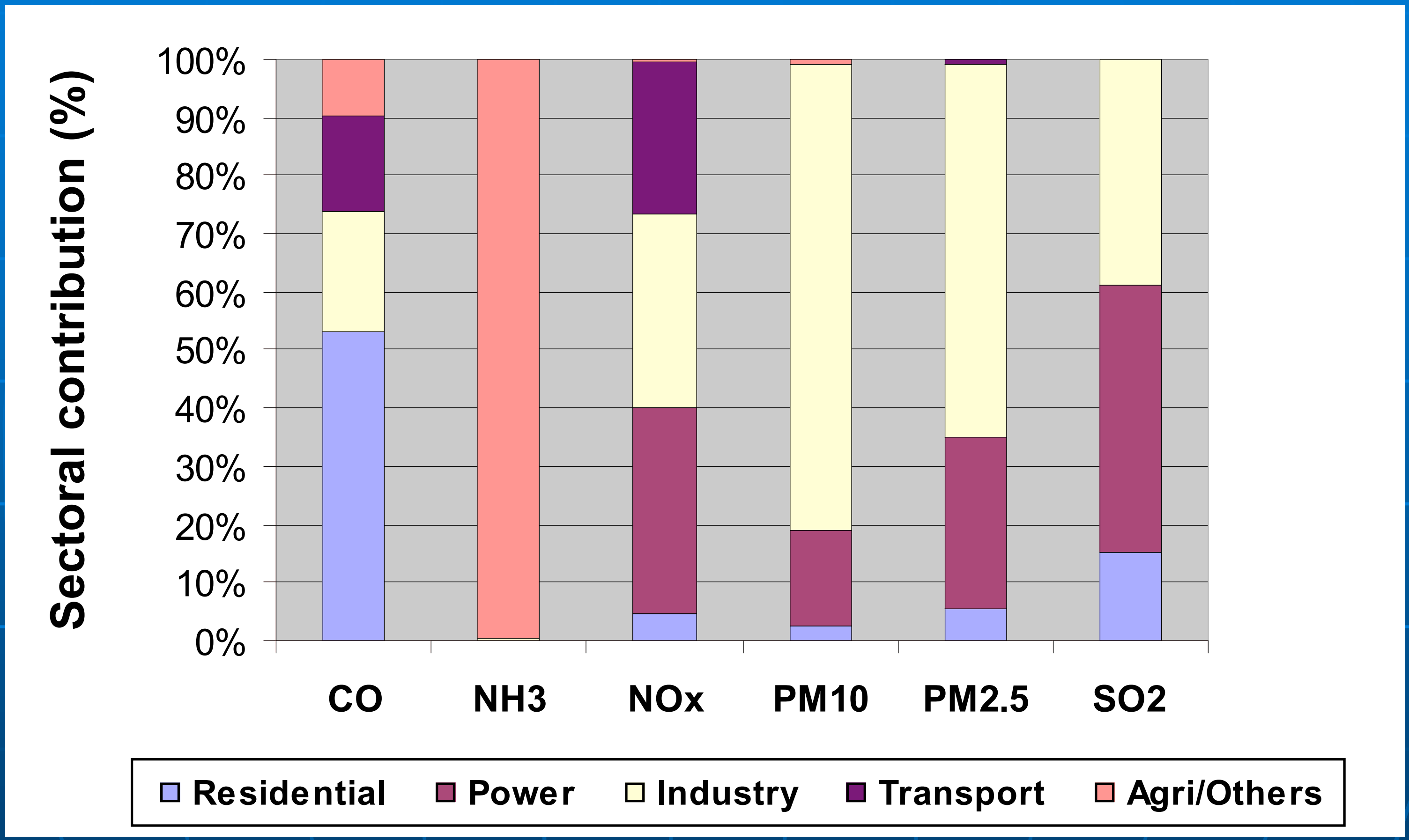
8 species(j): CO, NH_3, SO_2, NO_x, PM_{10}, $PM_{2.5}$, NMVOC, CO_2
87 municipalities (k), 72 source categories (l*m*n)

Data on activity levels is obtained from China's official statistics published at national, provincial and municipal levels.

Emission Inventory Development (2)



Emissions by Sector in 2000



SMOKE is used to process spatial and temporal allocation and chemical speciation of emissions.

Seasonal and diurnal cycles for emissions are included.

Projected 2020-to-2000 ratio for population, GDP and energy consumption of major fuels in Zaozhuang under BAU [Zheng et al., 2003]

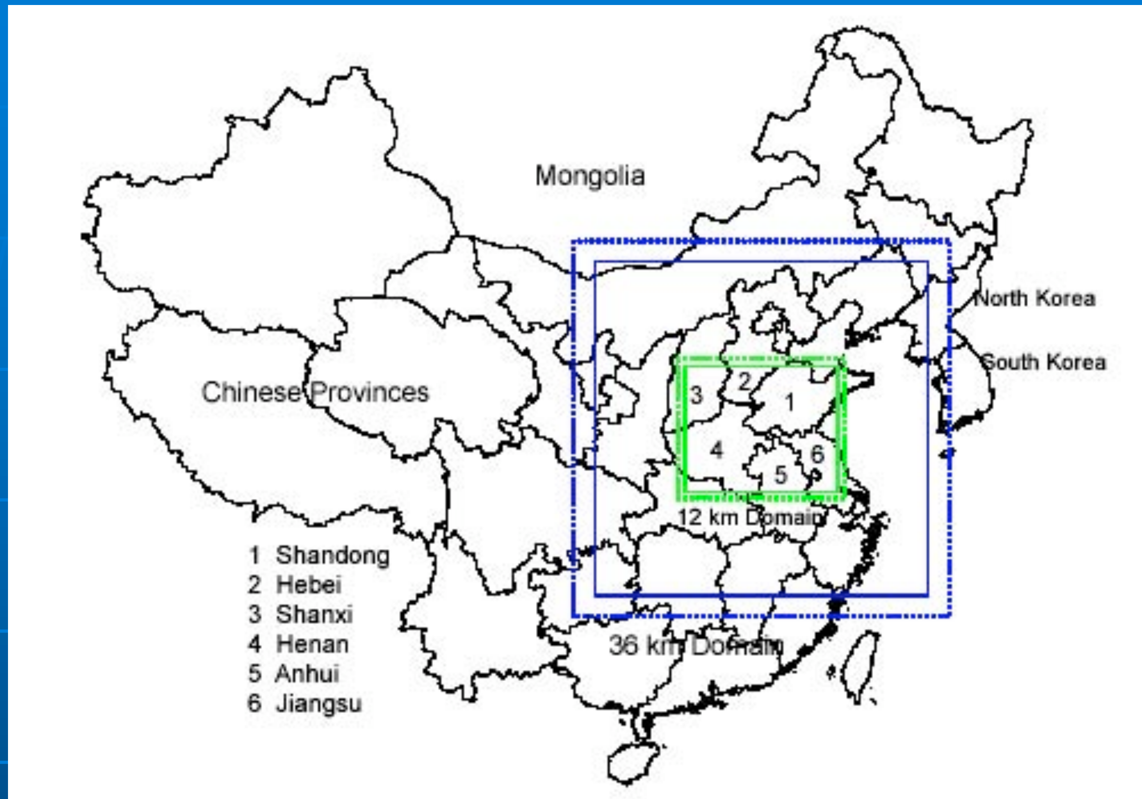
		2020-to-2000 Ratio
Population:		1.17
GDP:		5.6
	Primary (agricultural) sector	2
	Secondary (industry) sector	5.2
	Tertiary (service) sector	8
Urban residential final energy demand:		
	Raw coal	2.14
	LPG	6.73
	Town gas	1.49
Rural residential final energy demand:		
	Raw coal	10.3
	Biomass	1.22
	LPG	6.9
	Biogas	2.75

Projected 2020-to-2000 ratio for population, GDP and energy consumption of major fuels in Zaozhuang under the BAU [Zheng et al., 2003] (cont.)

		2020-to-2000 Ratio
Power:		
	Raw coal	3.18
	Washed coal	1.9
Transport:		
	Gasoline	2.62
	Diesel	2.32
Commercial:		
	Raw coal	0.9
	LPG	38.13
	Town gas	1.49

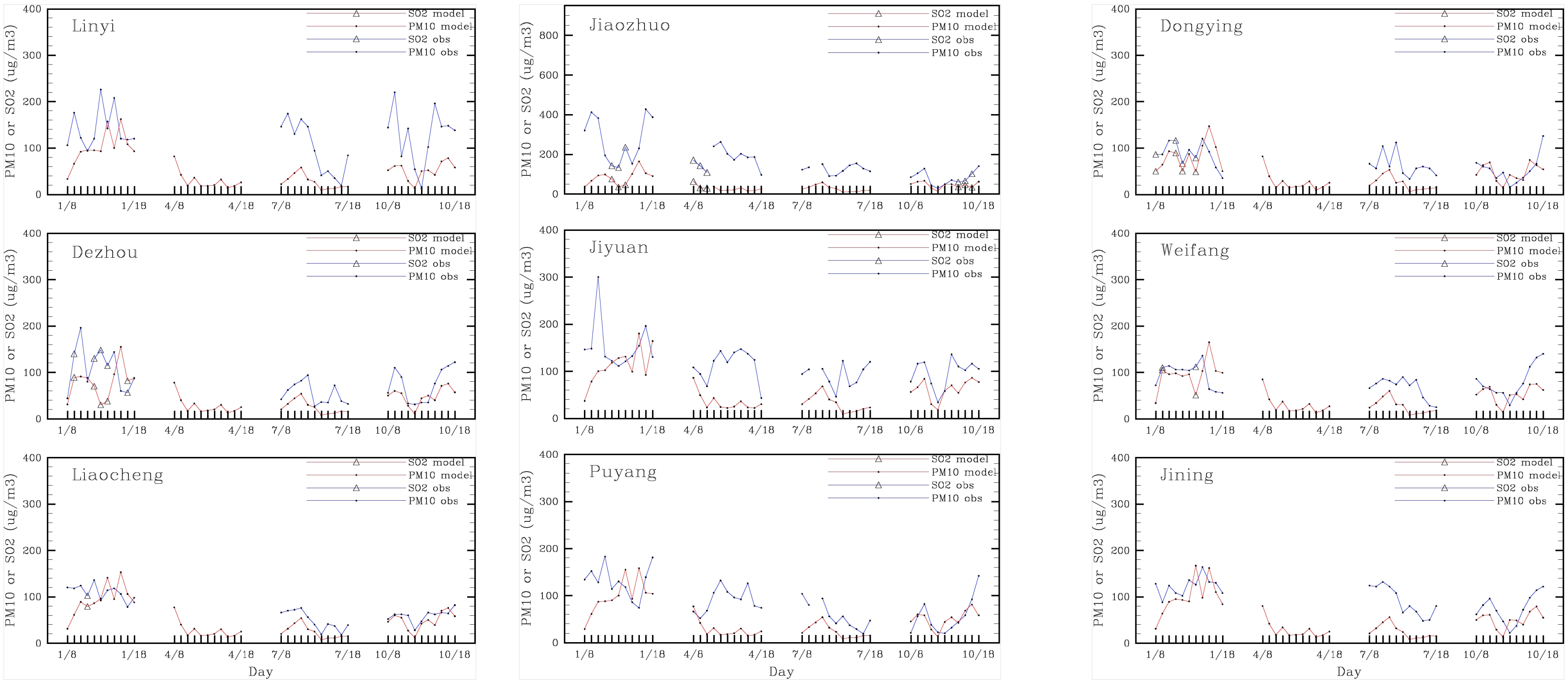
II. Model Simulations

Modeling Domain



High resolution emission inventory compiled for inner green region at $(12km)^2$ resolution.
Streets et al. inventory used for outer blue region at 36 km^2 resolution.
Solid lines indicate boundaries for CMAQ
Dashed lines indicate boundaries for MM5.
Boundary conditions for inner domain obtained from outer domain.
Boundary conditions for outer domain obtained from MOZART-2.

Comparison of CMAQ-simulated 2000 concentrations (red) with observations (blue) derived from APIs in 2002-2004



Model performance simulating ambient PM10 concentrations

	Annual Average	January	April	July	October
Sample size	1367	354	173	420	420
Observed PM_{10} concentrations ($\mu g/m^3$)	106	141	131	82	90
Modeled PM_{10} concentrations ($\mu g/m^3$)	53	98	30	25	51
Bias (model – obs) ($\mu g/m^3$)	-54	-43	-100	-57	-39

Main 2020 Technology Scenarios

Scenario	Main Characteristics
BAU	Energy and environmental control technologies and emission factors (EF) maintained at 2000 levels.
BACT	Energy technologies same as in 2000, but equipped with best available end-of-pipe controls such as desulphurization for power plants (90% reduction), catalytic converters on vehicles (70% reduction). Other sectors assume 20% reduction [*Zheng et al.*, 2003]
ACGT	Replace conventional coal combustion technologies with advanced coal gasification technologies with 24% penetration in Zaozhuang [*Larson and Ren*, 2003]

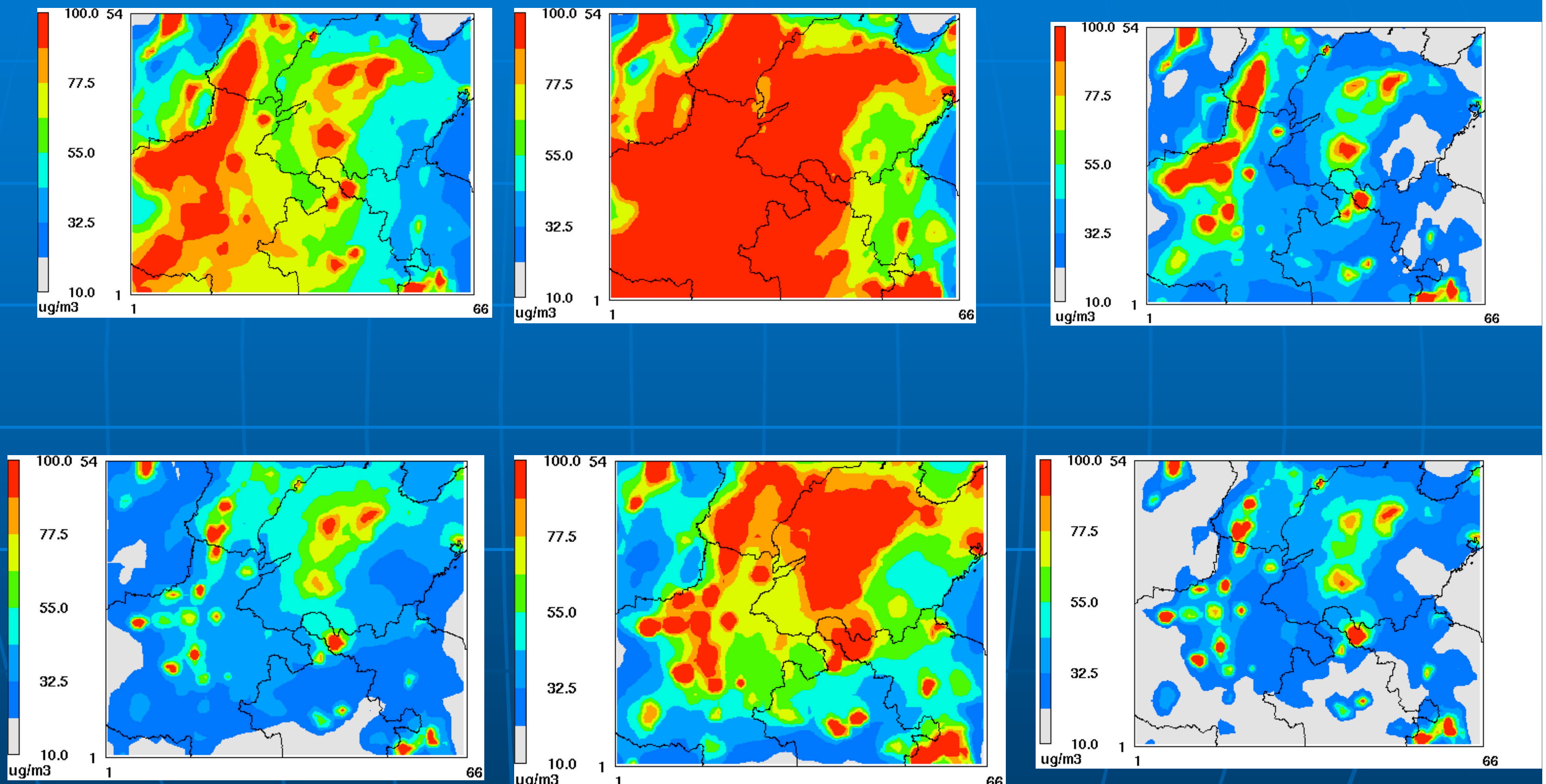
Changes in ambient concentrations required for the health impact analysis are calculated as the difference between two model simulations.

Seasonal variations of PM2.5 in 2000 and 2020 BAU

2000 | 2020BAU | 2020BAU - 2000

January

July



Compare to U.S.EPA PM2.5 standard:

- annual average limit of 15ug/m^3
- 24-hour limit of 65ug/m^3

PART III Health Impact Analysis

Estimating Mortality / Morbidity Effects

$$\Delta Cases = I_{ref} * Pop * \gamma * \Delta c$$

ΔCases = annual change in mortalities or morbidities resulting from air pollution exposure

I_{ref} = annual baseline mortality / morbidity rate

Pop = size of affected population

γ = relative risk per unit change in concentrations

Δc = annual change in ambient concentrations

Cohort study CR coefficients are used to calculate mortalities resulting from air pollution exposure on adults 30+ years [*Pope III et al*., 2002] and on infants <1year [*Woodruff et al*., 1997]. Time series studies are used to estimate morbidities.

Years of life lost (YOLL) estimates use *Leksell and Rabl* [2001]

Estimating Economic Values for Mortality and Morbidity

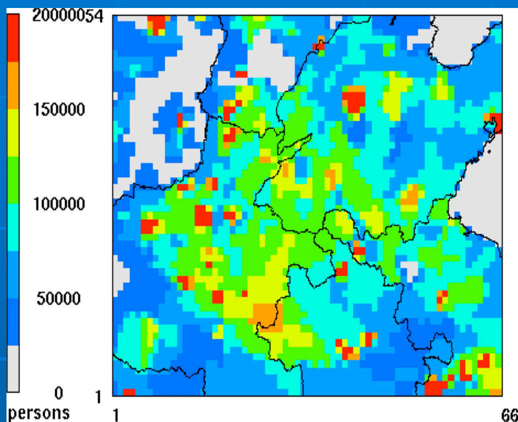
- ΔHealth costs = Δcases *unit value of each case

- Obtaining consensus on valuation is difficult
  - Willingness to pay vs. Human Capital
  - Value of a Statistical Life (VSL) vs. Years of Life Lost (YOLL)
  - Costs of illness

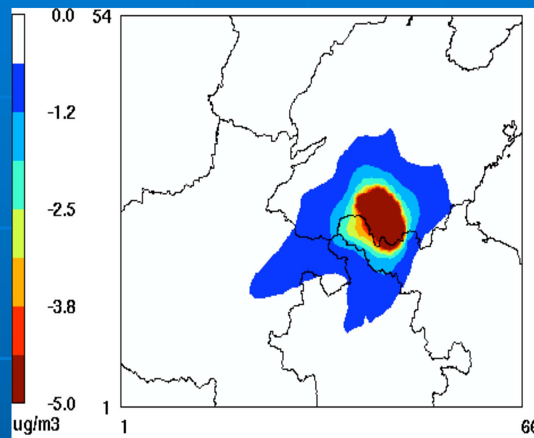
- We use Chinese WTP study giving VSL of $34,583 in 2000 and adjust it by projected increase in per capita income in China in 2020 to $163,350.

Effect of Zaozhuang 2000 Emissions on Mortality and Morbidity (Zero anthro emissions from Zaozhuang – 2000)

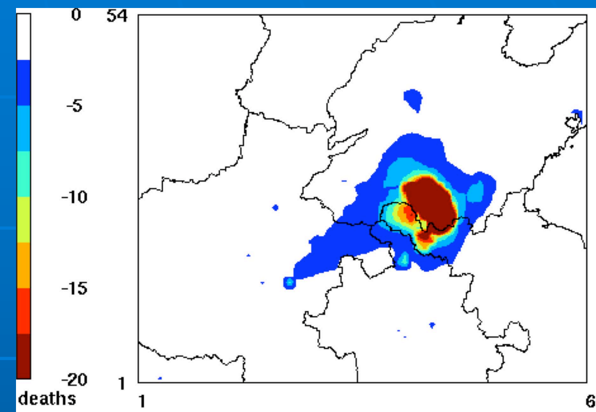
2000 Population



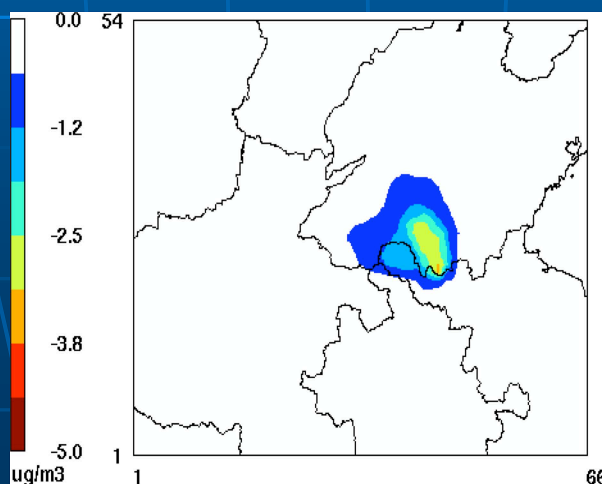
D total PM2.5



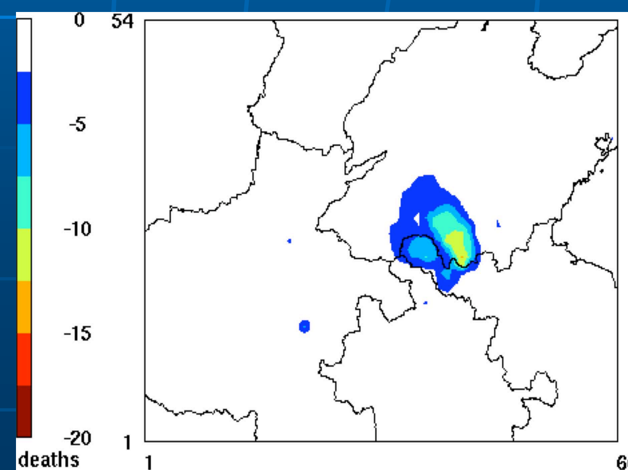
Mortalities Averted Due to DPM2.5



D secondary PM2.5

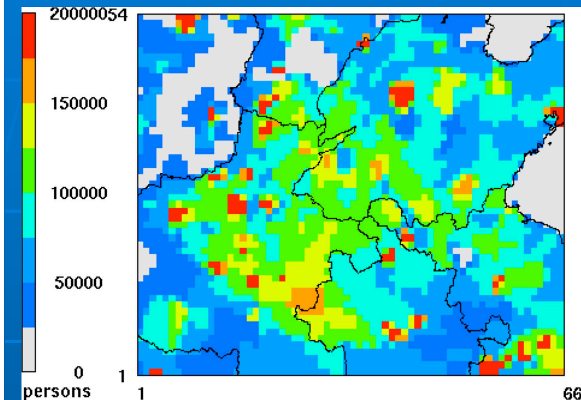


Mortalities Averted due to Dsecondary PM2.5

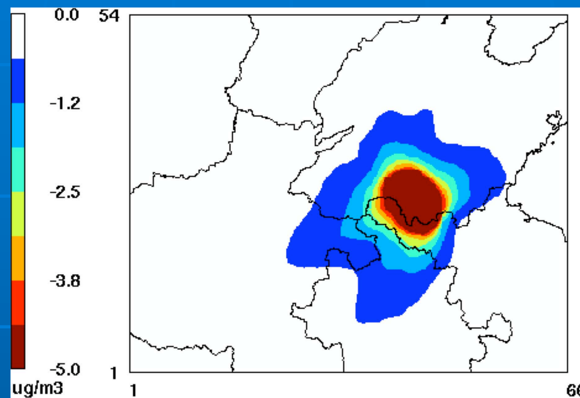


Effect of Zaozhuang 2020 Emissions on Mortality and Morbidity (Zero anthro emissions from Zaozhuang – 2020BAU)

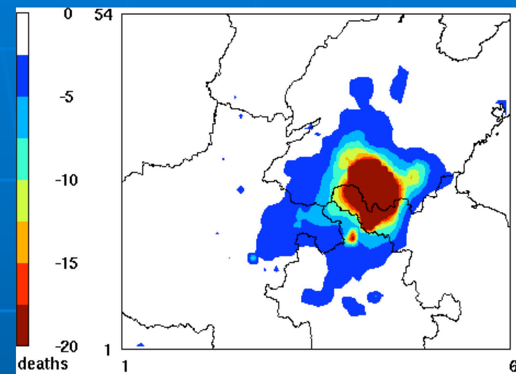
2020 Population



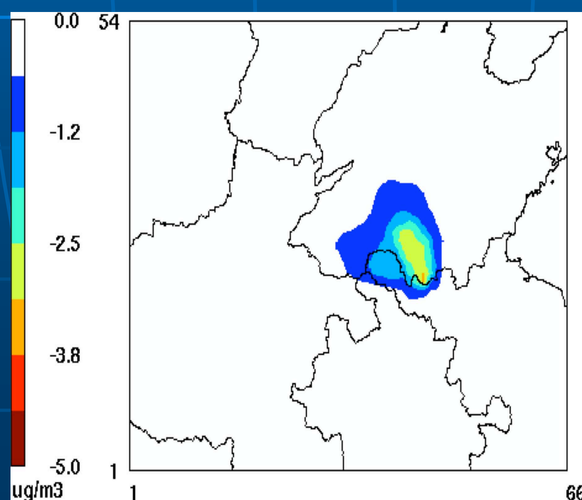
DPM2.5



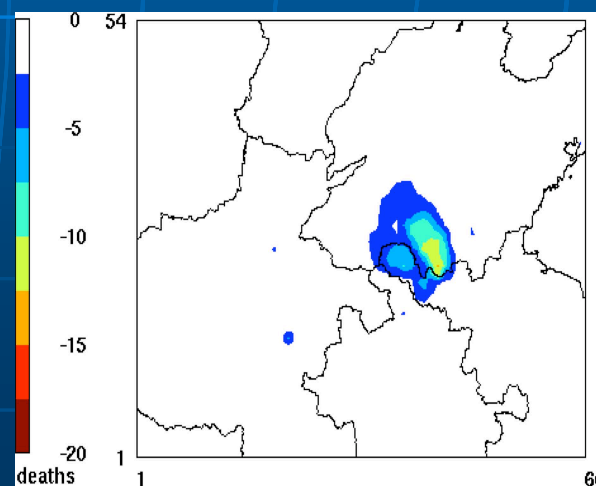
Mortalities Averted Due to DPM2.5



Dsecondary PM2.5

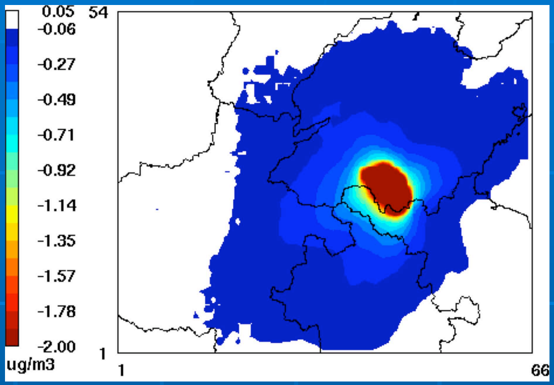


Mortalities Averted due to Dsecondary PM2.5

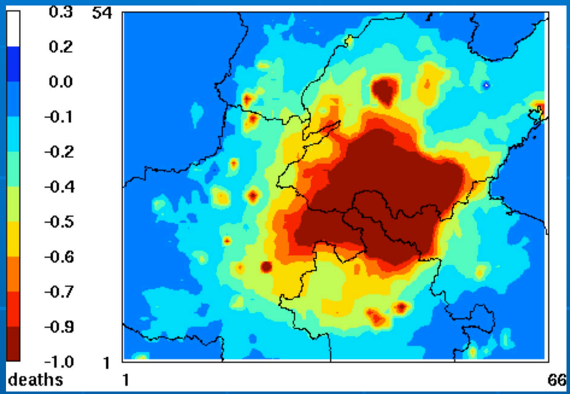


Effect of Changes in Zaozhuang’s 2020 Energy Technology on Emissions and Mortalities

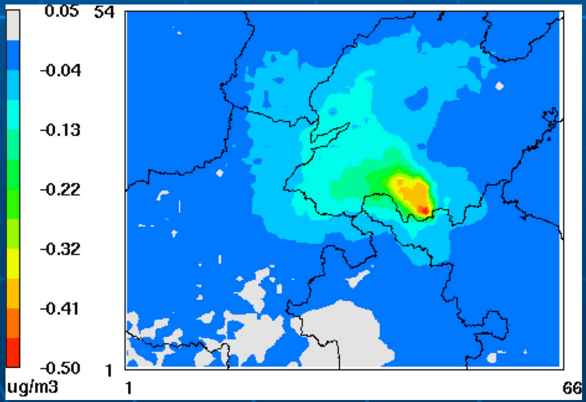
Benefits of BACT - BAU



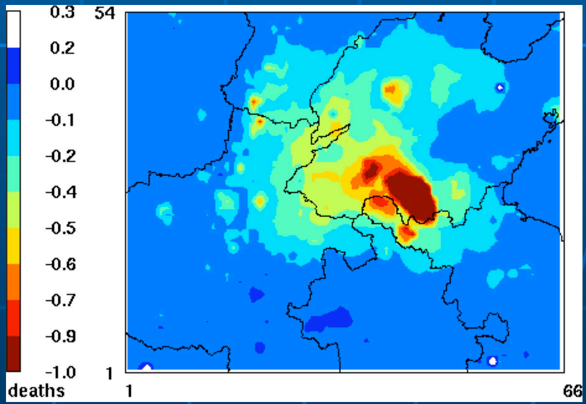
Decrease in Total PM2.5



Mortalities Averted Due to total DPM2.5



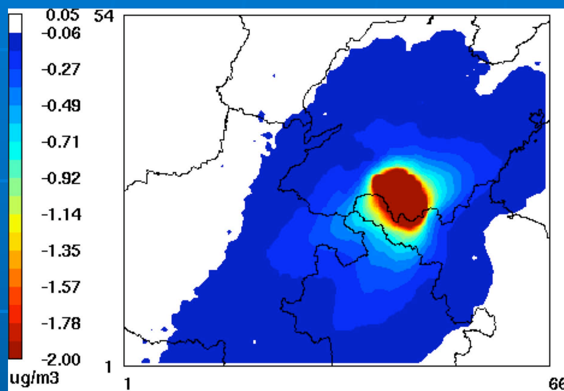
D secondary PM2.5



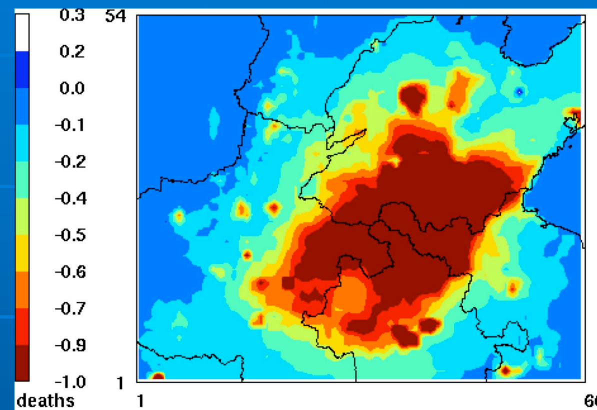
Mortalities Averted due to Dsecondary PM2.5

Effect of Changes in Zaozhuang's 2020 Energy Technology on Emissions and Mortalities

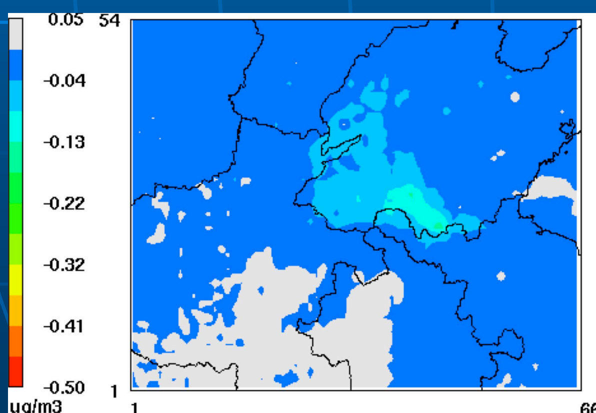
Benefits of ACGT - BAU



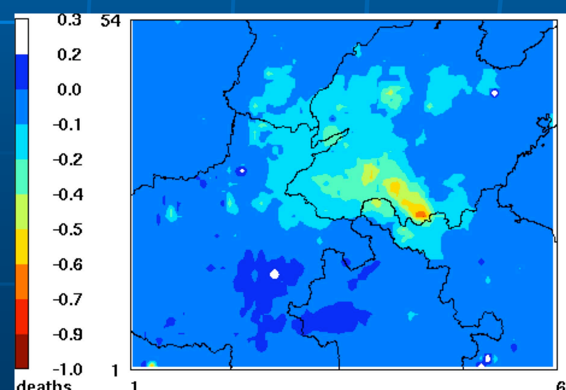
Decrease in Total PM2.5



Mortalities Averted
Due to total DPM2.5



Dsecondary PM2.5



Mortalities Averted due
to Dsecondary PM2.5

Summary – Year 2000 Results

- Health damages from PM dominate air pollution impacts.
- In 2000, ~6000 deaths (20 persons/million people exposed) were caused by anthropogenic emissions from Zoazhuang, 25% occurring in Zaozhuang and the rest in the surrounding area. Approximately 42,000 YOLL.
- Total economic damage of health impacts in 2000 are estimated to be $0.15 billion (YOLL + illness) - $0.28 billion (death + illness). This is equivalent to 5-10% of Zaozhuang's 2000 GDP.
- If health costs were internalized, the market price of coal should have doubled.

Summary – 2020 BAU Results

- In 2020BAU, ~10,700 deaths would occur due to increased energy consumption and population growth; approximately 75,000 YOLL.

- Total economic value of health damages from 2020BAU emissions is $1.5 billion (YOLL + illness) to $2.7 billion (death + illness), equivalent to 9-16% of projected 2020 GDP in Zaozhuang.

- If environmental externalities were truly reflected in the market price of coal, the 2020 coal price should be 5 times higher than in 2000 (rather than constant as expected).

Summary – 2020 BACT and ACGT Results

- If Zaozhuang **substitutes BACT for BAU** in 2020 (with 100% market share of energy services), 2500 deaths would be avoided annually (34% reduction).

- Economic benefits of reduced health impacts resulting from **substituting BACT for BAU** in Zaozhuang are $0.2 billion (YOLL + illness) to $0.6 billion (death + illness).

- If Zaozhuang **substitutes ACGT** (with approximately 25% penetration) **for BAU**, 5200 deaths would be avoided.

- Economic benefits of reduced health impacts resulting from **substituting ACGT for BAU** in Zaozhuang with 24% penetration are $0.8 billion (YOLL + illness) to $1.4 billion (death + illness).

- Relative to BAU 20%-50% of health damages from air pollution could be avoided by adopting BACT or ACGT.

- Changes in energy technology can have an enormous benefit for public health. The Shandong region would benefit from increased emission controls and even more from a change in energy services to coal gasification.

Summary -- Overall

- Economic costs of health impacts from air pollution arising from coal combustion in eastern China was large in 2000 and is potentially enormous in 2020 if no additional emission controls are implemented.

- Public health would benefit from increased emission controls and even more from a change in energy services to coal gasification technologies.

- Emission of reactive air pollutants and CO_2 can both be controlled through the use of ACGT. Strategic energy technology choices can simultaneously address emissions of CO_2 and air pollutants.

Emission inventory development described in:

Wang, X, **Mauzerall, D. L.**, Hu, Y., Russell, A. G., Larson, E. D., Woo, J-H., Streets, D. G., Guenther, A., "A High-Resolution Emission Inventory for Eastern China in 2000 and Three Scenarios for 2020," *Atmospheric Environment,* submitted, November 2004.

Health impact of air pollution described in:

Wang, X., **Mauzerall, D.L**., Evaluating Impacts of Air Pollution in China on Public Health: Implications for Future Air Pollution and Energy Policies, *Environmental Health Perspectives*, submitted, December 2004.

Both papers are available at:
http://www.wws.princeton.edu/mauzerall/